

Remarks

Claims 1-106 remain pending in the present application.

Objections to the preliminary amendments to the claims

In the Office Action, the Examiner objected to the technical presentation in which underlining and brackets were used to indicate earlier amendments to certain claims in this reissue application, and required a follow-up corrective amendment of the relevant claims. As such, the Applicants again present the minor amendments to claims 24-36, 39-45, 48-50, 56, 59, 61, 62, 69, 70, 76-79, 82, 84, 86, 90, 91, 92, 95, 96 and 100, and new claims 105 and 106, all as already considered by the Examiner. In particular, the entire text of each of the new reissue claims is now underlined and unchanged with respect to this Response.

The Applicant thanks the Examiner for having already considered the merits of each of these claims. With this technical correction, it is respectfully requested that the objection be withdrawn.

Rejection of claims 24-38, 42, 50, 51, 59, 61, 62, 77 and 86 under 35 U.S.C. §112, 1<sup>st</sup> paragraph.

In the Office Action, claims 24-38, 42, 50, 51, 59, 61, 62, 77 and 86 were rejected under 35 U.S.C. §112, 1<sup>st</sup> paragraph for allegedly lacking support in the specification for a recited feature.

In particular, the Examiner alleges that the claimed repetition rate of "at least 20 Hz" lacks proper support in the specification.

Specific support for the claimed feature can be found, for example, *inter alia*, in the parent application filed on December 3, 1992, on page 19, line 25 (copy attached for the Examiner's convenience), and in the present reissue application on page 11, line 32.

As disclosed in the December 3, 1992 parent application, an exemplary pulsed laser has a "high-repetition-rate [of] 20 – 100 Hz." This range

clearly supports the language "pulse repetition rate of at least 20 Hz" as recited in claims 24-38, 42, 50, 51, 59, 61, 62, 77 and 86. Therefore, all claims are in full compliance with the requirements of 35 U.S.C. §112, 1<sup>st</sup> paragraph.

Accordingly, the Applicant respectfully requests that the rejection be withdrawn.

Rejection of claims 3, 4 and 8-10 under 35 U.S.C. §112, 2<sup>nd</sup> paragraph.

In the Office Action, claims 3, 4 and 8-10 were rejected under 35 U.S.C. §112, 2<sup>nd</sup> paragraph for allegedly being indefinite.

In particular, the Examiner alleged that the range of energy level recited by claims 3, 4 and 8-10 was outside the range recited by claim 1 from which the rejected claims depend.

The typographical error in claim 1 is amended herein to now recite more clearly an energy level of no greater than 10 mJ/pulse (i.e., inclusive of 10 mJ/pulse), providing claim 1 with the same language already recited in current claims 3, 4 and 10 (which were previously allowed and published in the subject patent).

All claims being in full compliance with 35 U.S.C. §112, it is respectfully requested that the rejection be withdrawn.

Rejection of claims 69, 70, 73-75 and 99-103 under 35 U.S.C. §102(e).

In the Office Action, claims 69, 70, 73-75 and 99-103 were rejected under 35 U.S.C. §102(e) as allegedly being anticipated by U.S. Patent 5,144,630 to Lin (hereinafter "'630 Patent").

The '630 Patent has common inventorship with the present application, and therefore is not "by another" as required by 35 U.S.C. §102(e).

In particular, 35 U.S.C. §102(e) provides, in pertinent part:

**35 U.S.C. 102 Conditions for patentability; novelty and loss of right to patent.**

A person shall be entitled to a patent unless –

(e) the invention was described in a patent granted on an application for patent **by another** filed in the United States before the invention thereof by the applicant for patent (Emphasis Added).

The '630 Patent and the present application share the same inventive entity, namely, J. T. Lin, both as a sole inventor. Thus, the '630 Patent is not "by another". See MPEP §2136.04. See *a/so In re Land*, 151 USPQ 621 (CCPA 1966) ("Another" means other than applicants").

Accordingly, since the '630 Patent is not prior art to the claims of the present application under 35 U.S.C. § 102(e), the present rejection relying on the '630 Patent is improper. Accordingly, the Applicant respectfully requests withdrawal of the rejection.

Rejection of claims 24-47, 69-80, 82-86, 89-98 and 106 under 35 U.S.C. §102(a).

In the Office Action, claims 69, 70, 73-75 and 99-103 were rejected under 35 U.S.C. §102(a) as allegedly being anticipated by International Publication No. WO 93/08877 (of international application number PCT/US92/09625) by Lai (hereinafter "Lai"). The Applicants did not receive a copy of the Lai reference with the Office Action, but have obtained a copy at their own expense.

It is respectfully submitted that Lai is not prior art to the claims of the present application because all claims are fully supported by the parent application filed on December 3, 1992.

In particular, the claim to priority of the present reissue application is of record, as acknowledged on the filing receipt for the present reissue application (copy attached). The present reissue application is a reissue of Serial No. 08/218,319, filed on March 25, 1994, now U.S. Patent No. 5,520,679, which is a CIP of Serial No. 07/985,617, filed on December 3, 1992 ("the Parent Application"), now abandoned. A claim of priority to the Parent Application has been and is hereby expressly made.

Moreover, as described in the Declaration And Power Of Attorney For Reissue Application By Assignee And Inventor filed with the Reissue application at pages 6 and 7, all claims are fully supported by the Parent

Application filed on December 3, 1992<sup>1</sup> and are entitled to the December 3, 1992 priority date.

<sup>1</sup> For the Examiner's convenience, citations to various supporting passages from the Parent Application filed on December 3, 1992 for each of the new claims of the reissue application are reproduced in their entirety herein below:

#### Support for New Claims

No new matter has been added by new claims 24 through 104. Support for each of the following new claims can be found in the parent Application Serial No. 07/985,617, filed on December 3, 1992, inter alia as follows:

New claim 24 at page 6, line 19, page 10, line 20, and page 19, line 25;  
New claims 25, 49, 79, 84 and 95 at page 6, lines 12-13;  
New claims 26, 50 and 96 at page 15, line 7;  
New claim 27 at page 19, line 14;  
New claims 28-31, 40 and 57-59 at page 13, line 10 and page 19, line 16;  
New claims 32, 41, 60, 72 and 97 at page 13, line 9;  
New claims 33, 34, 43, 62, 70 and 93 at page 10, line 15;  
New claims 35, 44 and 63 at page 15, lines 22-23;  
New claims 37, 46 and 65 at page 23, lines 1-2;  
New claims 38, 47, 66 and 89 at page 23, line 17;  
New claims 39 and 76 at page 13, lines 9-13, and page 15, line 7;  
New claims 42, 61 and 92 at page 19, line 25;  
New claim 48 at page 6, line 11, page 14, lines 8-10, page 15, line 22 through page 16, line 7, page 23, lines 21-29, and Figs. 6A-6D;  
New claim 51 at page 22, line 9;  
New claim 52 at page 6, line 14;  
New claim 53, 54, 73 and 74 at page 6, line 11;  
New claim 55 at page 4, line 29;  
New claim 56 at page 19, line 14;  
New claims 67 and 68 at page 23, lines 1-20, and Fig. 6B;  
New claim 69 at page 15, line 22 to page 16, line 7, page 23, lines 21-29, and Figs. 6A through 6D.  
New claim 75 at page 6, line 13;  
New claim 80 at page 15, lines 22-33;  
New claims 81 and 87 at page 14, lines 8-10;  
New claims 82, 83 and 98 at page 13, lines 5-9, and 15, line 7;  
New claim 85 at page 6, line 21;  
New claim 86 at page 4, line 28;  
New claims 91 and 99 at page 6, line 18 to page 7, line 12;  
New claims 102 and 103 at page 18, lines 10-11; and  
New claim 104 at page 19, line 22.

Support for each of the following new claims can be found in Application Serial No. 08/218,319, filed on March 25, 1994, inter alia as follows:

New claims 36, 45, 64, 78 and 94 at page 15, line 7, page 27, line 26 in combination with page 29, line 16;  
New claim 77 at page 32, line 5; and  
New claims 100 and 101 at pages 9 and 10.

Support for new claim 90 can be found at patent claim 1.

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Thus, as can be easily confirmed, the priority date for all claims of the present reissue application (including those listed in the present rejection) is December 3, 1992.

Lai is a publication of an international patent application. Lai was published on May 13, 1993, more than 6 months AFTER the earliest priority date of all claims of the present reissue application. As such, Lai is not prior art to any of the claims of the present reissue application.

35 U.S.C. §102(a) provides, in pertinent part::

35 U.S.C. 102 Conditions for patentability; novelty and loss of right to patent.

A person shall be entitled to a patent unless - -

- (a) the invention was known or used by others in this country, or patented or described in a printed publication in this or a foreign country, before the invention thereof by the applicant for a patent. (Emphasis Added)

As specifically provided by 35 U.S.C. §120<sup>2</sup>, the effective filing date of all claims that are supported by the earlier filed Parent Application is December 3, 1992.

Thus, Lai is not prior art with respect to the current claims of the reissue application. Accordingly, the Examiner's express acknowledgement of the claim to priority would be respectfully appreciated. Moreover, the Applicant respectfully requests a withdrawal of the rejection.

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<sup>2</sup> 35 U.S.C. §120 provides:

**35 U.S.C. 120 Benefit of earlier filing date in the United States.**

An application for patent for an invention disclosed in the manner provided by the first paragraph of section 112 of this title in an application previously filed in the United States, or as provided by section 363 of this title, which is filed by an inventor or inventors named in the previously filed application shall have the same effect, as to such invention, as though filed on the date of the prior application, if filed before the patenting or abandonment of or termination of proceedings on the first application or on an application similarly entitled to the benefit of the filing date of the first application and if it contains or is amended to contain a specific reference to the earlier filed application. (Emphasis Added)

Rejection of claims 1, 3, 11-23, 48-68, 81, 87, 88 and 105 under 35 U.S.C. §103(a) in view of Lai and Bille.

In the Office Action, claims 1, 3, 11-23, 48-68, 81, 87, 88 and 105 were rejected under 35 U.S.C. §103(a) as allegedly being obvious in view of Lai and US Patent 4,901,718 to Bille et al. (hereinafter "Bille").

In order for a reference to be a prior art under 35 U.S.C. §103, the reference must also be prior art under 35 U.S.C. §102. See MPEP 2141.01. See also Panduit Corp. v. Dennison Manufacturing Co., 810 F.2d 1561, 1 USPQ2d 1593, 1597 (Fed. Cir.), *cert. denied*, 481 U.S. 1052 (1987) ("Before answering [a] 'content' inquiry, it must be known whether a patent or publication is in the prior art under 35 U.S.C. 102.").

As discussed above, the priority date of all claims of the present reissue application is December 3, 1992, which pre-dates Lai. Therefore, Lai is not prior art with respect to claims 1, 3, 11-23, 48-68, 81, 87, 88 and 105.

The present rejection cannot and does not stand on Bille alone, as evidenced by the Examiner's need to combine it with Lai as a primary reference in alleging grounds for the present rejection. Accordingly, it is respectfully requested that the rejection be withdrawn.

Rejection of claims 2 and 4-10 under 35 U.S.C. §103(a) in view of Lai and Bille and in further view of the '630 Patent to Lin.

In the Office Action, claims 2 and 4-10 were rejected under 35 U.S.C. §103(a) as allegedly being obvious in view of Lai and Bille, and in further view of the '630 Patent to Lin.

As discussed herein above, Lai is not prior art to the claims of the present reissue application. Moreover, as discussed, the '630 patent to Lin is by the same inventor as the present application, and thus is also not prior art to the presently rejected claims.

Bille alone cannot and does not support the present rejection, as evidenced by the Examiner's use of two other references to support an alleged

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obviousness argument. Accordingly, it is respectfully requested that the rejection be withdrawn.

Rejection of claims 99-104 under 35 U.S.C. §103(a) in view of Lai and the '630 Patent.

In the Office Action, claims 99-104 were rejected under 35 U.S.C. §103(a) as allegedly being obvious in view of Lai and the '630 Patent to Lin.

For the reasons already discussed, neither Lai nor the '630 Patent to Lin constitutes prior art with respect to the claims of the present reissue application, which all claim priority from, and are fully supported by, the Parent Application filed on December 3, 1992.

Accordingly, the Applicant respectfully requests that the rejection be withdrawn.

Conclusion

All objections and rejections having been addressed, it is respectfully submitted that the subject application is in condition for allowance and a Notice to that effect is earnestly solicited.

Respectfully submitted,



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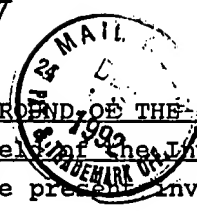
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OPHTHALMIC SURGERY METHOD USING  
NON-CONTACT SCANNING LASER



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1 BACKGROUND OF THE INVENTION

2 1. Field of the Invention

3 The present invention relates to laser ophthalmic  
4 surgery using a refractive laser and is concerned with  
5 compact, low-cost, low-power laser systems using a  
6 computer-controlled, non-contact process and corneal  
7 topography to perform corneal reshaping using either  
8 surface ablation or thermal coagulation.

9 2. Prior Art

10 Various lasers have been used for ophthalmic  
11 applications including the treatments of glaucoma,  
12 cataract and refractive surgery. For the  
13 non-refractive treatments (glaucoma and cataract), the  
14 suitable laser wavelengths are in the ranges of  
15 visible to near infrared. They include : Nd:YAG (1064  
16 nm), doubled-YAG (532 nm), argon (488, 514 nm).  
17 krypton (568, 647 nm), semiconductor lasers (630-690  
18 nm, 780-860 nm) and tunable dye lasers (577-630 nm).  
19 For refractive surgeries (or corneal reshaping),  
20 ultraviolet(UV) lasers (excimer at 193 nm and  
21 fifth-harmonic of Nd:YAG at 213 nm) have been used for  
22 large area surface corneal ablation in a process  
23 called photorefractive keratectomy (PRK). Corneal  
24 reshaping may also be performed by laser thermal  
25 coagulation currently conducted with Ho:YAG lasers  
26 using a fiber-coupled, contact-type process. However,  
27 the existing ophthalmic lasers as above described have  
28 one or more of the following limitations and  
29 disadvantages: high cost (due to the high-power  
30 requirement in such as UV lasers for photorefractive  
31 keratectomy, large size and weight, high maintenance  
32 cost and gas cost (for excimer laser), and high  
33 fiber-cost (for contact-type laser coagulation).

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1 In light of the above, it is an object of the  
2 present invention to provide ophthalmic laser systems  
3 which offer the advantages of: low-cost, reduced size  
4 and weight, reliable, easy-operation and maintenance.  
5 Another object of this invention is to provide a  
6 computer-controlled scanning device which enables use  
7 of a low-cost, low-energy lasers for photorefractive  
8 keratectomy currently performed only by high-power UV  
9 lasers.

10 It is yet another object of the present invention  
11 to provide a refractive laser system which is compact,  
12 portable and insensitive to environmental conditions  
13 (such as vibration and temperature). This portable  
14 system may also be used for a mobile clinical center  
15 where the laser is transported by a van. It is yet  
16 another objective of the present invention to provide  
17 a non-contact process for corneal reshaping using  
18 laser thermal coagulation, where predetermined corneal  
19 correction patterns are conducted for both spherical  
20 and astigmatic changes of the corneal optical power.

21 There are several prior art U.S. Patents relating  
22 to the refractive surgery, or photorefractive  
23 keratectomy. A UV solid-state fifth-harmonic of  
24 Nd:YAG (or Nd:YLF) laser at 213 nm (or 210 nm), is  
25 disclosed in U.S. Pat. No. 5,144,630 by the  
26 inventor, J.T. Lin. U.S. Pat. No. 4,784,135 suggests  
27 the use of a UV laser with wavelengths less than 200  
28 nm, in particular Argon Fluoride (ArF) laser at 193  
29 nm, for non-thermal photo-ablation process in organic  
30 tissue. Devices for beam delivery and methods of  
31 corneal reshaping are disclosed in U.S. Pat. No.  
32 4,838,266 using energy attenuator, and U.S. Pat. No.  
33 5,019,074 using an erodible mask. Techniques for  
34 corneal reshaping by varying the size of the exposed

1 region by iris or rotating disk are discussed in  
2 Marshall et al, "Photoablative Reprofileing of the  
3 Cornea Using an Excimer Laser: Photorefractive  
4 Keratectomy" Vol. 1, Lasers in Ophthalmology, pp.  
5 21-48 (1986). Tangential corneal surface ablation  
6 using ArF excimer laser or harmonics of Nd:YAG laser  
7 (at 532 and 266 nm) was disclosed in U.S. Pat. No.  
8 5,102,409.

9 This prior art however requires high UV energy of  
10 (30-40) mJ per pulse delivered onto the corneal  
11 surface, where large area corneal ablation using a  
12 beam spot size of about (4-6) mm which gives an energy  
13 density of (120-200) mJ/cm<sup>2</sup>. Moreover, the prior art  
14 Argon Fluoride excimer lasers operate at a repetition  
15 rate of (5-15) Hz and also limit the practical use of  
16 the tangential ablation concept which takes at least  
17 (5-10) minutes for a -5 diopter corneal correction in  
18 a 5-mm optical zone. The high energy requirement of  
19 the currently used Argon Fluoride excimer laser  
20 suffers the problems of: high-cost (in system,  
21 erodible mask and gas cost), high-maintenance cost,  
22 large size/weight and system are sensitive to  
23 environmental conditions (such as temperature and  
24 moisture).

25 One of the essential feature of the present  
26 invention for the photorefractive keratectomy process  
27 is to use a scanning device in a laser system which  
28 has high repetition rates, 50 to 50,000 Hz, but  
29 requires less energy, ~~ranging between 0.05-10 mJ~~ per  
30 pulse. This new concept enables one to make the  
31 refractive lasers at a lower cost, smaller size and  
32 with less weight (by a factor of 5-10) than that of  
33 prior art lasers. Furthermore, these compact lasers

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1 of the present invention are portable and suitable for  
2 mobile clinical uses. To achieve beam uniformity and  
3 fast refractive surgery (30 to 60 seconds), a  
4 mathematical model of the beam overlap and ablation  
5 speed is also disclosed in the present invention.

6 For the laser thermokeratoplasty (LTK) process,  
7 the prior art uses fiber-coupled contact-type  
8 procedure which involves the following drawbacks: (i)  
9 slow processing speed (typically a few minutes to  
10 perform eight-spot coagulation) which causes the  
11 non-uniform collagen shrinkage zone; (ii) circular  
12 coagulation zone which limits the procedure only for  
13 spherical type correction such as hyperopia; and (iii)  
14 the contact fiber-tip must be replaced in each  
15 procedure.

16 In the present invention, a computer-controlled  
17 scanning device is able to perform the laser  
18 thermokeratoplasty procedure under a non-contact mode  
19 and conduct the procedure many times faster than that  
20 of the prior contact-procedure and without cost for a  
21 fiber-tip replacement. Furthermore the coagulation  
22 patterns can be computer predetermined for specific  
23 applications in both spherical and astigmatic  
24 corrections. The flexible scanning patterns will also  
25 offer uniform and predictable collagen shrinkage.

26 For ophthalmic applications, it is another  
27 objective of the present invention to include but not  
28 limited to photorefractive keratectomy, laser  
29 thermokeratoplasty, epikeratoplasty, intrastroma  
30 photokeratectomy (IPK) and phototherapeutic  
31 keratectomy (PTK).

1 SUMMARY OF THE INVENTION

2 Toward this end and according to the present  
3 invention, the preferred embodiments of the basic  
4 laser system for the ophthalmic surgery process  
5 includes the following systems: (1) a diode-pumped  
6 solid-state lasers of Nd:YAG or Nd:YLF which is  
7 frequency-converted by nonlinear crystals of KTP  
8 (potassium titanyl phosphate), LBO (lithium  
9 triborate), KNbO<sub>3</sub> (potassium niobate) and BBO (beta  
10 barium borate) into the fifth-harmonic at wavelength  
11 of 213 nm or 210 nm with energy of 0.01 to 0.05 mJ;  
12 (2) a compact, low-cost, low-power (energy of 1 to 10  
13 mJ per pulse) argon fluoride excimer laser at 193 nm;  
14 (3) a frequency-converted diode-laser at (193-215) nm;  
15 (4) a compact, low-cost, Q-switched Er:YAG laser at  
16 2.94 microns; and (5) a free-running Ho:YAG (at 2.1  
17 microns) or Er:glass (at 1.54 microns).

18 According to one aspect of the present invention,  
19 the above-described basic lasers includes UV-lasers  
20 (193-215 nm) and IR-laser <sup>2.5-3.2</sup> ~~(2.94 microns)~~ which are  
21 focused into a spot size of <sup>0.05-7</sup> ~~(0.1-2)~~ mm in diameter,  
22 where laser energy per pulse of (0.01-10) mJ is  
23 sufficient to achieve the photo-ablation threshold  
24 (PAT) energy density of 50 to 160 mJ/cm<sup>2</sup> depending upon  
25 the laser parameters (wavelengths and pulse duration)  
26 and tissue properties (absorption and scattering).  
27 The prior art excimer laser uses large beam spot  
28 ablation (4-6 mm) and require much higher laser energy  
29 (30-40 mJ) than the low-power lasers presented in this  
30 invention. In the present invention, a scanning,  
31 non-contact device is used to control the low-power  
32 laser for corneal diopter change, whereas diaphragm or  
33 mask are used in the high-power, high-cost excimer

1 lasers, and contact, fiber-tip is used in the  
2 photo-coagulation procedure.

3 In another aspect of the present invention, a  
4 mathematical model is presented according to the  
5 optimal beam overlap for beam uniformity and fast  
6 procedure and scanning patterns for refractive  
7 corrections of myopia, hyperopia and astigmatism. For  
8 high-repetition lasers (50 to 5,000 Hz as proposed  
9 herein), refractive procedures may be completed in 20  
10 to 60 seconds (depending on the diopter corrections)  
11 in the present invention, where scanning speed is only  
12 limited by the laser repetition rates.

13 A three-dimensional translation device (in X, Y  
14 and Z) is integrated into the above laser systems,  
15 where the laser heads are compact and light-weight and  
16 can be steered to the corneal center by the  
17 translation stages. The prior art high-powered excimer  
18 laser systems are stationary and require a motorized  
19 chair for corneal centration. Beam steering  
20 and scanning is very difficult for these high-power,  
21 heavy-weight excimer lasers.

22 In yet another aspect of the present invention, a  
23 free-running Ho:YAG ( at 2.1 microns) or Er:glass (at  
24 1.54 microns) laser delivers a beam by a fiber  
25 waveguide and coupled to a scanning device for  
26 non-contact procedure for laser thermokeratoplasty  
27 (LTK), where optimal scanning patterns for corneal  
28 coagulation are performed for both spherical and  
29 astigmatic corrections.

30 In yet another aspect of the present invention,  
31 the above-described laser system provides an  
32 effective, low-cost tool for procedures of synthetic  
33 epikeratoplasty (SEK), where the artificial lens is  
34 sculpted with the laser to optimize lens curvature

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1 without causing problems of corneal haze and  
2 corrective regression. Real corneal tissues may also  
3 be sculpted and implanted by the above-described laser  
4 systems, a procedure known as laser myopic  
5 keratomileusis (MKM). Furthermore the UV and IR lasers  
6 disclosed in the present invention provide an  
7 effective tool for phototherapeutic keratectomy (PTK)  
8 which is currently conducted by high-power excimer  
9 lasers and the procedure conducted by diamond-knife  
10 called radial keratotomy (RK). This procedure  
11 conducted by UV or IR lasers is called laser  
12 radial keratotomy (LRK). The fundamental beam at 1064  
13 or 1053nm wavelength of the present invention may also  
14 be used for the intrastroma photorefractive  
15 keratectomy (IPK), where the laser beam is focused  
16 into the intrastroma area of the corneal and collagen  
17 tissue are disrupted.

18 To summarize, the ophthalmic applications of the  
19 laser systems described in the present invention  
20 should include but not limited to: photorefractive  
21 keratectomy, phototherapeutic keratectomy, laser  
22 thermokeratoplasty, intrastroma photokeratectomy,  
23 synthetic epikeratoplasty, and laser radial  
24 keratotomy.

#### 25 BRIEF DESCRIPTION OF THE DRAWINGS

26 Fig. 1 is a block diagram of computer-controlled  
27 refractive laser system consisting of the basic laser,  
28 scanning device, power supply and the beam steering  
29 stage for ophthalmic applications;

30 Fig. 2 is a block diagram for the generation of  
31 ultraviolet wavelengths at 213 nm or 210 nm using  
32 nonlinear crystals in a diode-pumped system;

1 Fig. 3 is a block diagram of a computer-controlled  
2 refractive laser system of Ho:YAG or Er:glass in a  
3 non-contact scanning mode for laser  
4 thermokeratoplasty;

5 Figs. 4A through 4E shows computer-controlled  
6 scanning patterns for photo-coagulation in non-contact  
7 LTK procedures for both spherical and astigmatic  
8 corneal reshaping;

9 Figs. 5A and 5B are procedures for laser-assisted  
10 myopic keratomileusis and hyperopic keratomileusis,  
11 where the reshaping can be performed either on the  
12 inner or outer part of the tissue;

13 Figs. 6A through 6D show computer-controlled beam  
14 overlap and scanning patterns for myopic, hyperopic  
15 and astigmatic correction using UV (193, 210, 213 nm)  
16 or IR (<sup>0.75-3.2</sup>~~2-9.4~~ microns) lasers;

17 Figs. 7A and B are laser radial keratectomy  
18 patterns (LRK) using laser excisions for myopia  
19 (radial-cut) and astigmatism (T-cut); and

20 Figs. 8A through 8D shows ablation patterns for  
21 refractive correction using predetermined coatings on  
22 UV or IR grade windows.

#### 23 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

24 The theoretical background of the present invention  
25 with regards to the beam overlap and ablation rate in  
26 photorefractive keratectomy, intrastroma  
27 photokeratectomy, synthetic epikeratoplasty,  
28 phototherapeutic keratectomy and myopic keratomileusis  
29 procedures described in the present invention is as  
30 follows. Portions of the theoretical background was  
31 published by the inventor, J. T. Lin, in SPIE Pro. vol  
32 1644, Ophthalmic Technologies II (1991), p.p. 266-275.



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1 Given a laser energy per pulse of  $E$  (in mJ), an  
2 intensity of  $I$  (in mJ/cm<sup>2</sup>) may be achieved by focusing  
3 the beam into an area of  $A$ , where  $I=E/A$ . For corneal  
4 tissue ablation to occur requires the laser intensity  
5 ( $I$ ) to be above the photoablation threshold (PAT),  
6 (60-120) mJ/cm<sup>2</sup> for UV-laser (193, 210 or 213 nm) and  
7 (200-600) mJ/cm<sup>2</sup> for IR-laser (<sup>0.75-3.2</sup>~~2.94~~ <sup>42</sup>microns).  
8 Therefore it is always possible to tightly focus a  
9 laser beam and achieve the PAT value even for a  
10 low-energy laser (0.1-5) mJ. The drawback of using a  
11 low-energy, small-spot laser for large area ablation  
12 is that the operation time will be longer than that of  
13 a large-spot but high-power laser. However, time of  
14 operation may be shortened by using a  
15 high-repetition-rate laser (higher than 50 Hz).  
16 Small-spot, low-energy lasers for large area surface  
17 ablation would become practical only when a scanning  
18 device is used in a high-repetition-rate laser and  
19 only when uniform beam profile can be assured by the  
20 appropriate beam overlap. These two important issues  
21 are addressed in the present invention.

22 The overall operation rate ( $R$ ) for a given diopter  
23 correction ( $D$ ) is limited by the laser scanning rate  
24 ( $R_1$ ) which is in turn limited by the laser repetition  
25 rate. In addition,  $R$  is also proportional to the  
26 tissue ablation rate ( $R_T$ ) which is proportional to the  
27 laser intensity  $I$  (or energy density) at a given  
28 energy  $E$ .

29 The diopter change ( $D$ ) in the case of myopia is  
30 related to the correction zone diameter ( $W$ ) and the  
31 center ablation thickness ( $h_0$ ) and the ablation  
32 profile  $h(x)$  (at corneal position  $x$ ) by:

$$1 \quad h(x) = h_0 + 1.32DW^2 \quad (1)$$

$$2 \quad h_0 = -0.3315DW^2 \quad (2)$$

3 In a scanning system as disclosed in the present  
4 invention, the number of ablation layers (M1) (without  
5 beam overlap) required for D-diopter correction is  
6 therefore related to the ablation thickness per pulse  
7 (T1), D, and W by

$$8 \quad M1 = h_0/T1 = -0.3315DW^2/T1 \quad (3)$$

9 To include the overlap factor (F), F=2 for a 50% beam  
10 overlap scan and F=5 for 80% overlap, the required  
11 effective number of overlapped ablation layers is  
12 M1/F.

13 For a given ablation zone of W and laser focused  
14 spot area of A, one requires an effective single-layer  
15 scanning time (TS) of  $FW^2/A$ .

16 The total operation time (T) needed for h0 center  
17 ablation or D-diopter correction becomes

$$18 \quad T \propto (M1/F)(TS) \quad (4) \\ \propto DW^4/E$$

19 Equation 4 gives us the scaling-law for operation  
20 time required (T), the laser energy (E), diopter  
21 change (D) and the ablation zone diameter (W). For a  
22 given laser energy per pulse of E, the overall  
23 operation rate (1/T) is independent to the laser  
24 intensity (I) and beam spot size (A). By increasing  
25 the laser average-power (P), defined by laser  
26 energy/pulse x repetition rate, more total energy may  
27 be delivered to the cornea per unit time. The  
28 average-power (P) is the key factor which actually

1 determine the overall operation rate (or time)  
2 required to achieve the diopter change. By realizing  
3 that the scanning rate (1/TS) is proportional and  
4 synchronized to the laser repetition rate (RP), we are  
5 able to re-express Eq. (4) as

6  $T \propto DW^4/P$  (5).

7 It is important to note that given an  
8 average-power of P, the laser intensity must be above  
9 the photo-ablation threshold (PAT) by either beam  
10 focusing or increase the laser energy (~~fluency per~~  
11 pulse).

12 Based upon the above-described theory, we are able  
13 to summarize some important features accordingly: (i)  
14 CW lasers (either UV or IR) with low intensity  
15 normally can not cause photo-ablation since the energy  
16 density is lower than the PAT value; (ii) Lasers (UV or  
17 IR) at ~~Q-switched mode~~ and with pulse-duration shorter  
18 than ~~100~~ <sup>10</sup> nanosecond will normally achieve the  
19 intensity above the PAT even at low-energy level of  
20 0.05-5 mJ. In particular, ~~picosecond~~ <sup>nanosecond</sup> lasers at high  
21 repetition rate would be one of the favor candidates,  
22 where energy in the micro joule range would be  
23 sufficient. Moreover, the Q-switched short pulse  
24 lasers have smaller thermal damage than that of  
25 free-running lasers. The cost-effective refractive  
26 lasers shall be those which have high repetition rates  
27 (50 Hz and up) but operated at low-energy (~~0.05-5 mJ~~ <sup>0.005-5 mJ</sup>)  
28 and short pulse duration (~~0.01-100 nanoseconds~~ <sup>0.001-20 nanoseconds</sup>). The  
29 preferred embodiments disclosed in the present  
30 invention as discussed in Fig. 1 are based upon this  
31 theory behind. Beam focusing and scanning are always  
32 required to achieve the PAT and smooth ablation

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1 profile. We also note that the individual beam profile  
2 in the scanning system is not as critical as that of  
3 the prior art lasers which require a uniform overall  
4 profile within the large ablation zone of (4-6) mm.  
5 In our laboratory we have achieved very smooth  
6 ablation profile with zone diameter up to 8 mm  
7 starting from a non-uniform focused beam profile which  
8 were randomly scanned over the ablation zone of (1-8)  
9 mm. Using overlap of (50-80)% of focused beam spot of  
10 (0.5-1) mm, typical number of pulses delivered to the  
11 corneal surface is (1,000-2,000) which assures the  
12 sufficient beam overlap for smooth profile and  
13 pulse-pulse energy fluctuation is not critical.

14 Referring to Fig. 1, a refractive laser system in  
15 accordance with the present invention comprises a  
16 basic laser 10 having UV (193 nm, 213 nm or 210 nm) or  
17 ~~IR~~ (2.94 microns) wavelength 11 coupled by a scanning  
18 ~~AS~~ device 12 having the beam from focusing optics 14  
19 directed onto a reflecting mirror 15 into target 16  
20 which target may be the cornea of an eye. An arming  
21 system 17 has a visible wavelength (from a laser diode  
22 or He-Ne laser) 18 adjusted to be collinear with the  
23 ablation beam 11 and defines the centration of the  
24 beam onto the cornea surface at normal incident. The  
25 basic laser head 20 is steered by a motorized stage  
26 for X and Y horizontal directions 21 and the vertical  
27 (height) direction 22 which assures the focusing beam  
28 spot size and the centration of the beam onto the  
29 cornea. The system has a computer controlled panel 23  
30 and wheels 24 for portable uses. The target 16  
31 includes a human cornea for applications of  
32 photorefractive keratectomy, phototherapeutic  
33 keratectomy and laser radial keratotomy (using the UV  
34 193, 210, 213 nm or IR 2.9 microns beam focused on the

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1 corneal surface area) and intrastroma photokeratectomy  
2 (using the 1064 or 1053 nm beam, or their  
3 second-harmonic, focused into the intrastroma area),  
4 and synthetic or real corneal tissues for applications  
5 of synthetic epikeratoplasty and myopic  
6 keratomileusis. The computer controlling panel 23 also  
7 provides the synchronization between the scanning gavo  
8 and the laser repetition rate. A commercially  
9 available galvanometer scanner made by General  
10 Scanning, Inc. is used in scanning the laser beam.

11 The laser systems described herein have been  
12 demonstrated using photorefractive keratectomy  
13 procedure with a diopter corrections up to -12 in PMMA  
14 plasty and -6 in corneal tissues. In the case of PMMA  
15 we have also measured the diopters by a <sup>lensometer</sup> lens meter  
16 with well-defined readings in the ranges of -1 to -12  
17 diopters. This data provides the evidence of  
18 predictable diopter corrections using the laser  
19 systems of the present invention. Furthermore,  
20 minimal tissue thermal damage of 0.3-1.0 microns were  
21 measured by TEM (transmission electron microscopy). In  
22 my measurements, I used the multi-zone (MZ) approach  
23 for high-diopter corrections (8-12), where the  
24 center zone is 3 mm and the correction power decreases  
25 when the zone increases from 4 mm to 6 mm. This multi-  
26 zone approach reduces the overall ablation thickness  
27 and hence reduces the haze effect.

28 Still referring to Fig. 1, the basis laser is  
29 according to the present invention includes a compact,  
30 optically-pumped (either flash-lamp or laser-diode  
31 pumped) lasers of Nd:YAG, Nd:YLF or the  
32 self-frequency-doubling crystal of NYAB (neodymium  
33 yttrium aluminum) with pulse duration of 0.05-20  
34 nanoseconds and repetition rate of 1-10,000 Hz. It is



1 The low-power laser systems described in the  
2 present invention can perform the procedures normally  
3 required in high-power systems because a scanning  
4 device is used to assure the uniform corneal ablation  
5 by beam overlap and the ablation threshold is  
6 achievable when small spot size is used even in a  
7 low-energy system.

8 Referring to Fig. 2, a preferred embodiment for  
9 the basic laser 10 of Fig. 1 having a UV wavelength  
10 includes a diode-pumped Nd:YAG (or Nd:YLF) 25 having  
11 a fundamental wavelength of 1064 nm (or 1053 nm) 26  
12 and is focused by a lens 27 into a doubling crystal 28  
13 (KTP, KNbO<sub>3</sub>, LBO or BBO) to generate a green  
14 wavelength 30 at 532 nm (or 527 nm). The green beam  
15 30 is further converted by a fourth harmonic crystal  
16 31 (BBO) to generate a UV wavelength 32 at 266 nm (or  
17 263 nm) which is finally converted by a fifth harmonic  
18 crystal 33 to generate the UV wavelength 11 at 213 nm  
19 (or 210 nm). From a commercially available  
20 diode-pumped Nd:YLF laser I am able to achieve the UV  
21 (at 210 nm) energy of 0.01-0.05 mJ per pulse with  
22 average-power of 50 to 150 mW. This energy level when  
23 focused into a spot size of ~~(0.1-0.5)~~ <sup>0.05-0.5</sup> mm is sufficient  
24 to ablate the corneal tissue. This diode-pumped  
25 fifth-harmonic system provides the most compact  
26 refractive UV solid-state laser available today with  
27 the advantages of long lifetime, low maintenance,  
28 portability and absence of toxic gas in comparison  
29 with the excimer lasers currently used by other  
30 companies, such as Summit Technology, Inc. and Visx  
31 Inc. Furthermore by using the fundamental wavelength  
32 at 1064 nm (or 1053 nm) or their second-harmonic (at  
33 532 or 527 nm), intrastroma photokeratectomy procedure  
34 may be performed by focusing the beam into the

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1 intrastroma area of the cornea. The laser presented  
2 in the present invention provide a compact, portable  
3 and low-cost IPK laser and has an advantage over the  
4 lasers used by other companies, such as Phoenix Laser  
5 Systems Inc. and Intelligent Surgical Lasers, Inc.,  
6 where the systems are currently more than five times  
7 heavier and are more costly.

8 In Fig. 3, a commercially available Ho:YAG (or  
9 Er:glass) laser 35 (either flash-lamp or laser-diode  
10 pumped) is coupled by a fiber optic waveguide 36 with  
11 core diameter of (100-600) microns to a scanning  
12 device 37, in which the fundamental beam 38 with a  
13 wavelength of 2.1 (or 1.54) microns which is  
14 collimated by a lens 40 and coupled to the scanning  
15 gavo 41 and focused by another lens 42 onto the beam  
16 splitters 43 and 44, and finally delivered to a target  
17 (such as a patent's corneal) 45. The IR (2.1 microns) ←  
18 laser beam 38 is collinear with the aiming beam 46  
19 (visible He-Ne or diode laser) and the patent corneal  
20 center is also defined by a commercial slit-lamp  
21 microscope station 47. The above-described apparatus  
22 offers the unique feature of non-contact laser  
23 thermokeratoplasty for precise coagulation in both  
24 spherical and astigmatic corneal power corrections  
25 with scanning patterns predetermined by a computer  
26 software hereinafter discussed. The focusing lens 28  
27 may be motorized for varying the focal point and thus  
28 varying the coagulation cone size for optimal results.

29 In the prior art of fiber-tip contact system, the  
30 precision of the coagulation zone and patterns are  
31 limited by doctors manual operation which is a much  
32 slower procedure than the computer controlled scanning  
33 device described in the present invention. The  
34 requirement of replacing the fiber-tip after each



1 operation is also a drawback of the prior art systems.  
2 The advantages of the present system includes:  
3 precision coagulation zone and spot size, flexible  
4 patterns for a variety of corrections, fast processing  
5 time and elimination of the need for fiber-tip  
6 replacement.

7 Still referring to FIG. 3, the basic laser 22 in  
8 accordance with the preferred embodiment of the  
9 present invention is a free-running or continuous-wave  
10 (CW) flash-lamp or diode-laser pumped Ho:YAG (at 2.1  
11 microns) or Er:glass (at 1.54 microns), with average  
12 power of 0.2-10 W, pulse duration of 200-2,000  
13 micro-seconds (if free-running). In the present  
14 invention, the IR wavelengths of 1.54 and 2.1 microns  
15 are chosen due to their strong tissue absorption which  
16 is required in the photo-coagulation processes.  
17 Similar lasing media of Ho:Tm:YAG and Ho:Tm:Cr:YAG is  
18 also included in the preferred embodiments of the  
19 present invention.

20 Figs. 4A through 4E summarize the possible  
21 coagulation patterns suitable for both spherical and  
22 astigmatic corneal reshaping in the LTK procedures in  
23 a cornea 50. Fig. 4-A with coagulation zone (CZ) of 5  
24 to 9 mm and spot number (SN) of (8-16) provides  
25 hyperopic corrections of 1-6 diopters; Fig. 4-B has a  
26 coagulation zone of 1-3 mm suitable for myopic  
27 corrections; Fig. 4-C has radial coagulation zone and  
28 spot number of 16-32, suitable for spherical hyperopic  
29 correction; Fig. 4-D has a coagulation zone of 1-9 mm  
30 and spot number of 50-200, suitable for precise  
31 coagulation control to stabilize and reinforce the  
32 collagen shrinkage tension; Fig. 4-E is designed for  
33 astigmatic change, where the coagulation patterns are  
34 chosen according to the corneal topography. By using

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1 the computer-controlled scanning, these patterns may  
2 be easily generated and predetermined according to the  
3 measured corneal topography of each patients. A  
4 combination of these patterns illustrated in Figs. 4-A  
5 to 4-E enables the treatment of patent's optical power  
6 correction in all aspects of myopia, hyperopia,  
7 astigmatism and their mixed vision disorder.  
8 Furthermore, laser parameters such as energy per  
9 pulse, spot size and scanning patterns also provide  
10 another degree of freedom for the laser  
11 thermokeratoplasty process which are not usually  
12 available in the prior art systems using the contact  
13 fiber-tip. The appropriate parameters relating to  
14 Fig. 4A-B are: laser energy per pulse of 5-50 mJ for  
15 free-running mode (200-400 micro-second duration),  
16 beam spot size of (0.1-1) mm, laser repetition rate of  
17 5-30 Hz, coagulation zone of (1-10)mm, spot number of  
18 8-200 spots and fiber core diameter of 100-600  
19 microns, for a flash-lamp-pumped system. Also  
20 disclosed is the use of a diode-pumped Ho:YAG either  
21 in a pulse-mode or continuous-wave (CW) mode. For a  
22 CW mode laser, energy of 10-100 mW is sufficient for  
23 coagulation when spot size of 0.05-0.5 mm is employed.  
24 In the diode-pumped system in CW mode or with a  
25 high-repetition-rate 20-100 Hz, a fast scanning  
26 enables completion of the coagulation procedures  
27 within 2-20 seconds depending upon the coagulation  
28 zone and spot number required. Fast scanning also  
29 provides a uniform collagen shrinkage unlike that of  
30 the prior art system using a manually operated  
31 fiber-tip which normally takes 1 to 5 minutes to  
32 complete in a multiple coagulation zone and high spot  
33 number. It is difficult to use manually operated  
34 fiber-tip to generate the precise patterns as

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1 illustrated in Fig. 4. which can be easily performed  
2 in the computer-controlled scanning device as  
3 disclosed in the present invention. The patient's eye  
4 motion and decentration is a problem for the prior art  
5 systems, but it is not a critical factor in the fast  
6 scanning device described herein.

7 Referring to Fig. 5, a laser-assisted myopic  
8 keratomileusis (MKM) and hyperopic keratomileusis  
9 (HKM) can be performed either on the outer corneal  
10 surface 51 or on the inner surface 52 to reshape the  
11 resected corneal tissue without materially effecting  
12 Bowman's layer. The preferred lasers are described in  
13 Fig. 1 including the UV (193-215 nm) and IR (2.94  
14 microns) lasers. The non-invasive laser-assisted  
15 procedure disclosed in the present invention has the  
16 advantages over the procedures of photorefractive  
17 keratectomy and laser thermokeratoplasty including  
18 being safer, more stable with a higher diopter change,  
19 and without materially affecting epithelium and  
20 Bowman's layer. In comparison with the conventional  
21 keratomileusis, the laser-assisted myopic  
22 keratomileusis and hyperopic keratomileusis do not  
23 require corneal freezing and can perform very high  
24 diopter change not available by radial keratotomy or  
25 photorefractive keratectomy. Laser-assisted corneal  
26 preshaping can also be employed for a donor cornea in  
27 the procedure currently performed by epikeratophakia.  
28 Details of conventional lamellar refractive surgery  
29 may be found in Leo D. Bores, Refractive Eye Surgery  
30 (Blackwell Scientific Pub., 1993), Chapter 10.

31 Figs. 6A through 6D shows a nearly flat-top beam  
32 profile achieved by overlapping a series of laser  
33 beams, where the degree of overlap, 50%-80%, depends  
34 on the individual beam profiles which are not required

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1 to be flat-top. In the present invention, the  
2 preferred individual beam profile is either a 70%  
3 Gaussain or a smooth symmetric profile. In the  
4 laboratory, I have demonstrated a smooth laser-ablated  
5 corneal surface with zone diameter of 3-6 mm by  
6 overlapping a large number of pulses, 500 to 2,000,  
7 each one having a spot size of 0.8-1.2 mm. Moreover  
8 smooth transition among the ablation zones were  
9 achieved without the transition zone steps found in  
10 prior art systems using mechanical diaphragms. In  
11 addition to the myopic and hyperopic scanning patterns  
12 of 6B and 6C, one of the significant features of the  
13 present scanning device is that it can generate  
14 predetermined patterns based upon the corneal  
15 topography for astigmatism correction (see 6D).  
16 Corneal scar may also be easily located by a  
17 topography and photoablated by a laser based on the  
18 computer-controlled scanning patterns. The preferred  
19 lasers for the procedures described in Fig. 6 are  
20 discussed in connection with Fig. 1.

21 Still referring to Fig. 6, the scanning schemes  
22 were tested by ablation on PMMA plasty. The computer  
23 software is based upon the mathematical model  
24 described earlier where the center ablation thickness,  
25 see equation (2), was equally spaced to define the  
26 associate scanning diameters. Given the ablation  
27 thickness per pulse and per ablation layer (at a given  
28 scanning diameter), one may easily obtain the overall  
29 corneal surface ablation profile, see equation (1).  
30 The numbers of required ablation layer is therefore  
31 proportional to the diopter change (D) and square of  
32 the ablation zone (W). The computer parameters  
33 designed in the present invention include: diopter  
34 change (d), optical zone diameter (W), and the degrees

1 of overlap in both tangential (TD) and radial (RD)  
2 direction of the scan patterns as shown in Figs. 6A  
3 through 6D. Smooth PMMA surface ablation was achieved  
4 by optimization of laser spot size, energy and the  
5 overlap parameters of TD and RD. My experimental data  
6 indicates that larger overlap provides smoother  
7 surface ablation, however, longer ablation time is  
8 required for a given diopter change, laser energy and  
9 repetition rate (RR). Larger RR, <sup>50 Hz and up</sup> ~~50-100 Hz~~, provides  
10 shorter ablation time which is typically in the range  
11 of (20-40) seconds for diopter changes of 2-8 in  
12 myopic treatment based upon my measurements. The  
13 prior art high-power excimer lasers with a typical RR  
14 of 5-10 Hz have difficulty in achieving the results  
15 described in the present invention using the present  
16 scanning device.

17 Still referring to Figs. 6, using the UV lasers  
18 (193, 210 and 213 nm) I have achieved ablation depths  
19 of (200-400) microns by overlapping (100-200) laser  
20 pulses, which give an ablation depth of <sup>0.2-0.4</sup> ~~0.2-0.4~~  
21 microns per pulse. The ablation depths are measured  
22 by adjusting the focal point of a standard microscope  
23 on the no-ablated area and the bottom of the ablated  
24 area. Ablation curves, ablation depth versus laser  
25 intensity, were obtained by varying the laser energy  
26 or the spot size. Given the ablation rate (ablation  
27 thickness per pulse), I am able to calibrate the  
28 number of pulses and the degree of beam overlap  
29 required to achieve the diopter change on the PMMA,  
30 where the diopters of the ablated PMMA are measured by  
31 the standard lensmeter. In vitro measurement of  
32 corneal tissue ablation can be calibrated according to  
33 the comparison of the ablation rate between PMMA and  
34 tissue. For myopic and hyperopic corrections, I have

1 used circular scanning patterns with beam overlap  
2 controlled by the tangential scanning speed and  
3 diameters of the adjoined circles. The preferred  
4 scanning scheme is from small circle to large circle.  
5 For example, given a laser spot size of 1 mm, a radial  
6 overlap of 50% will require the scanning circle to  
7 start from 1 mm diameter to 5 mm diameters with an  
8 increment of 0.5 mm for an optical zone of 5 mm.  
9 Furthermore, a tangential overlap of 50% will require  
10 the scanner to move at an angular speed of about 23  
11 degrees within the interval between each laser pulse.  
12 In my computer-controlled scanning device, software  
13 was developed to synchronize the laser repetition rate  
14 with the scanning gavo to control the above-described  
15 overlap patterns. In addition to the circular  
16 patterns described for myopic and hyperopic  
17 treatments, a linear scanning pattern was used in  
18 particular for the astigmatic correction, where  
19 angular speed with uniform overlap would be difficult  
20 to achieve in a circular pattern.

21 It is important to note that a uniform individual  
22 beam profile and energy stability of the laser, under  
23 our scanning device, are not critical in achieving an  
24 overall uniform ablation zone whereas they are very  
25 critical for the prior art systems using expanding  
26 iris devices. Given the ablation rate per overlapped  
27 circle, the overall diopter correction may be achieved  
28 by the appropriate increment in diameters of the  
29 expanding circles.

Referring to Figs. 7A and 7B, a laser radial keratectomy (LRK) performed by laser excision has advantages over the conventional diamond-knife radial keratotomy (RK) including higher predictability and reproductability by precise control of the excision

1 (or ablation) depth. Furthermore, using the scanning  
2 device of the present invention, laser radial  
3 keratotomy may be performed easily and rapidly with  
4 less dependance upon the surgeon's skill and  
5 experience. Corneal reshaping may be performed by  
6 controlling the laser parameters such as spot size,  
7 intensity, scanning speed, beam overlap, and the  
8 excision depth per pulse which typically ranges from  
9 0.2 to 0.5 microns. The excision depth precision of  
10 a laser is at least 10 times better than that of a  
11 knife. This "laser-knife" should be able to perform  
12 all the radial keratotomy procedures performed by a  
13 "diamond-knife" by using similar techniques to those  
14 introduced in the Book of Leo D. Bores, Refractive Eye  
15 Surgery, Chapters 8 and 9. Examples of laser radial  
16 keratotomy are shown in 7A for myopia (radial-cut) and  
17 7B for astigmatism (T-cut). The preferred lasers for  
18 laser radial keratotomy include the lasers described  
19 in Fig. 1.

20 Referring to Figs. 8A and 8D, the ablation  
21 patterns suitable for refractive procedures may be  
22 generated by using coated windows such as UV (or IR)  
23 grade fused silica, MgF, BaF or sapphire (when an IR  
24 laser is used), with preferred thickness of (0.5-2) mm  
25 and diameter of (8-15) mm. Referring to Fig. 8A,  
26 scanning laser beams 53 (at wavelength of UV or IR)  
27 with circular scanning pattern to deliver uniform (or  
28 constant) laser energy over the coated window 44 with  
29 coating specification (at UV or IR wavelength)  
30 according to the profile on the corneal tissue 55 (or  
31 PMMA surface) will also achieve the same pattern  
32 described by equation (1). Figs. 8B and 8C show the  
33 reflection profiles of the coated windows for myopia,  
34 hyperopia and astigmatism, respective, based on

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1 predetermined diopter changes. These coated windows  
2 disclosed in the present invention can be reused for  
3 cost effectiveness and has an advantage over the prior  
4 art system using the disposable mask which is costly  
5 and is difficult to provide reproducible results due  
6 to the non-uniform transmission or ablation properties  
7 of the mask.

8 While the invention has been shown and described  
9 with reference to the preferred embodiments thereof,  
10 it will be understood by those skilled in the art that  
11 the foregoing and other changes and variations in form  
12 and detail may be made therein without departing from  
13 the spirit, scope and teaching to the invention.  
14 Accordingly, the method and apparatus, the ophthalmic  
15 applications herein disclosed are to be considered  
16 merely as illustrative and the invention is to be  
17 limited only as set forth in the claims.



CLAIMS:

I claim:

- 1 1. A method of performing laser surgery on the  
2 eye comprising the steps of:  
3 selecting a scanning pulsed laser having an  
4 output laser beam of a predetermined frequency;  
5 coupling said output laser beam to selected  
6 focusing optics for focusing said output laser beam;  
7 directing said focused output laser beam in a  
8 predetermined overlapping scanning beam path with  
9 repetitive pulses onto a plurality of positions on a  
10 patient's eye, whereby a portion of a patient's eye is  
11 ablated at predetermined positions for correcting the  
12 patient's vision.
- 1 2. A method of performing laser surgery on the  
2 eye in accordance with claim 1 including the step of  
3 positioning said scanning laser focusing optics a  
4 predetermined distance from the surface of the  
5 patient's eye for scanning said patient's eye.
- 1 3. A method of performing laser surgery on the  
2 eye in accordance with claim 2 in which the step of  
3 selecting a scanning laser includes selecting a diode  
4 pumped UV laser having an output wavelength between  
5 193 and 215 nanometers.
- 1 4. A method of performing laser surgery on the  
2 eye in accordance with claim 2 in which the step of  
3 selecting a scanning laser includes selecting an  
4 excimer laser having a UV output wavelength of 193  
5 nanometers.

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1           11. A method of performing laser surgery on the  
2 eye in accordance with claim 10 in which the step of  
3 selecting focusing optics includes selecting focusing  
4 optics to produce a spot size of between 0.1 to 2  
5 millimeters.

1           12. A method of performing laser surgery on the  
2 eye in accordance with claim 2 in which the step of  
3 selecting a scanning laser includes selecting a said  
4 scanning UV laser.

1           13. A method of performing laser surgery on the  
2 eye in accordance with claim 2 in which the step of  
3 selecting a scanning laser includes selecting a said  
4 scanning infrared laser.

14. A method of performing laser surgery on the eye in accordance with claim 2 in which the step of selecting a scanning laser includes selecting a scanning laser having a laser beam with an energy density of 50 to 160 mJ/cm<sup>2</sup>.

1 15. A method of performing laser surgery on the  
2 eye in accordance with claim 14 in which the step of  
3 selecting a scanning laser includes selecting a  
4 scanning laser having an overlapping scanning pattern  
5 of two different sized spots positioned around eye for  
6 selective ablation.

1 16. A method of performing laser surgery on the  
2 eye in accordance with claim 2 in which the step of  
3 selecting a scanning laser includes selecting a  
4 scanning laser having an overlapping scanning pattern  
5 of radial aligned spots.

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1 17. A method of performing laser surgery on the  
2 eye in accordance with claim 2 in which the step of  
3 selecting a scanning laser includes selecting a  
4 scanning laser having an overlapping scanning pattern  
5 of concentric spots.

1 18. A method of performing laser surgery on the  
2 eye in accordance with claim 2 in which the step of  
3 selecting a scanning laser includes selecting a  
4 scanning laser having an overlapping scanning pattern  
5 of ring spots.

1 19. A method of performing laser surgery on the  
2 eye in accordance with claim 2 in which the step of  
3 selecting a scanning laser includes selecting a  
4 scanning laser having a scanning pattern of radial  
5 aligned slits.

1 20. A method of performing laser surgery on the  
2 eye in accordance with claim 2 in which the step of  
3 selecting a scanning laser includes selecting a  
4 scanning laser having an overlapping scanning pattern  
5 of parallel slits.

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1           21. A method of photo-ablating and photo-  
2 coagulating a portion of the cornea of the eye for  
3 reshaping the cornea comprising the steps of:  
4           selecting a scanning laser having a laser beam of  
5 a predetermined frequency;  
6           selecting a laser scanning mechanism for scanning  
7 said selected laser beam;  
8           selecting focusing optics for focusing said  
9 output laser beam;  
10          positioning said focusing optics a predetermined  
11 distance from a patient's eye for scanning the eye  
12 with said laser beam without physical contact with the  
13 eye;  
14          directing said focused laser beam in a  
15 predetermined overlapping scanning beam path onto a  
16 patient's eye with said selected laser scanning  
17 mechanism, whereby a portion of a patient's eye is  
18 ablated or coagulated using a low power laser beam  
19 having repetitive beam patterns applied at  
20 predetermined positions for correcting a patient's  
21 vision.

1           22. A method of photo-ablating a portion of the  
2 cornea of the eye for reshaping the cornea in  
3 accordance with claim 21 in which the step of  
4 selecting a scanning laser includes selecting a  
5 scanning laser having a circular scanning pattern for  
6 delivering uniform laser energy over repeated circular  
7 scans.

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1 23. A method of photo-ablating a portion of the  
2 cornea of the eye for reshaping the cornea in  
3 accordance with claim 21 in which the step of  
4 selecting a scanning laser includes selecting a  
5 scanning laser having a plurality of circular scanning  
6 patterns for delivering uniform laser energy over  
7 repeated circular scans.

1 24. A method of photo-ablating a portion of the  
2 cornea of the eye for reshaping the cornea in  
3 accordance with claim 21 including the step of  
4 selecting a coated window for directing said laser  
5 beam therethrough and onto the cornea of a patient's  
6 eye.

1 25. A method of photo-ablating a portion of the  
2 cornea of the eye for reshaping the cornea in  
3 accordance with claim 24 including the step of  
4 selecting a coated window of a UV grade fused silica  
5 for directing said laser beam therethrough and onto  
6 the cornea of a patient's eye.

1 26. A method of photo-ablating a portion of the  
2 cornea of the eye for reshaping the cornea in  
3 accordance with claim 24 including the step of  
4 selecting a coated window of a sapphire for directing  
5 an IR laser beam therethrough and onto the cornea of  
6 a patient's eye.

1 27. A method of photo-ablating a portion of the  
2 cornea of the eye for reshaping the cornea in  
3 accordance with claim 24 including the step of  
4 selecting a coated window of BaF for directing said  
5 laser beam therethrough and onto the cornea of a  
6 patient's eye.

1           28. A method of photo-ablating a portion of the  
2 cornea of the eye for reshaping the cornea in  
3 accordance with claim 2, including the step of  
4 selecting a coated window of MgF for directing said  
5 laser beam therethrough and onto the cornea of a  
6 patient's eye.

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OPHTHALMIC SURGERY METHOD USING  
NON-CONTACT SCANNING LASER

1 ABSTRACT

2 A refractive laser surgery process is disclosed  
3 for using compact, low-cost ophthalmic laser systems  
4 which have computer-controlled scanning with a  
5 non-contact delivery device for both photo-ablation  
6 and photo-coagulation in corneal reshaping. The basic  
7 laser system may include flash-lamp and diode pumped  
8 UV lasers (193-215 nm), compact excimer laser (193  
9 nm), free-running Er:glass (1.54 microns), Ho:YAG (2.1  
10 microns) and Q-switched Er:YAG (2.94 microns). The  
11 advantages of the non-contact, scanning device used in  
12 the process over other prior art lasers include being  
13 safer, reduced cost, more compact and more precise and  
14 with greater flexibility. The theory of beam overlap  
15 and of ablation rate and coagulation patterns is also  
16 disclosed for system parameters. Lasers are selected  
17 with energy of (0.01-10) mJ, repetition rate of  
18 (1-10,000), pulse duration of 0.05 nanoseconds to a  
19 few hundreds of a micro-second, and with spot size of  
20 (0.1-2) mm for use with various refractive laser  
21 surgery.

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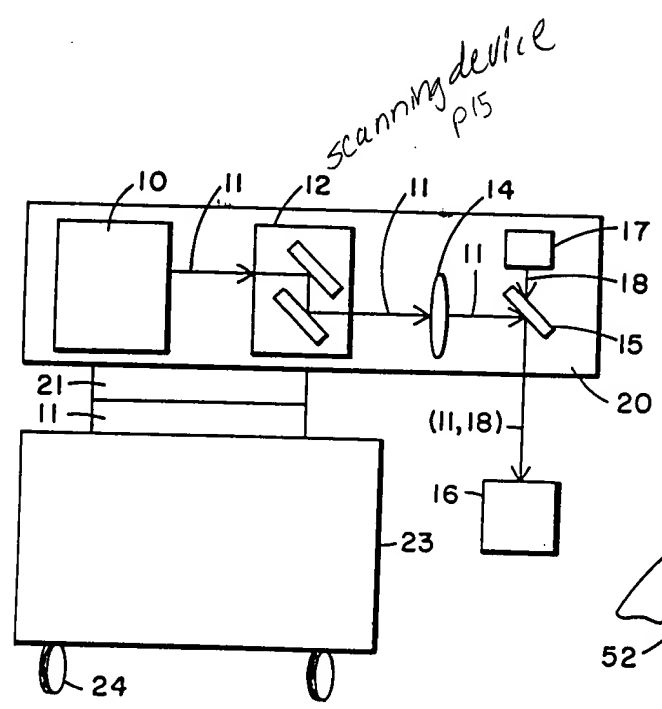


FIG. 1

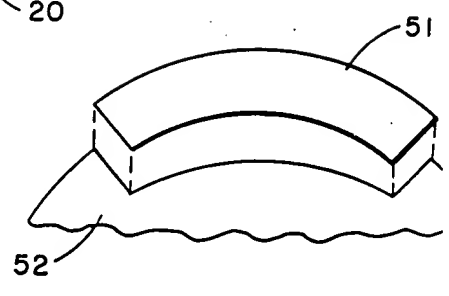


FIG. 5A

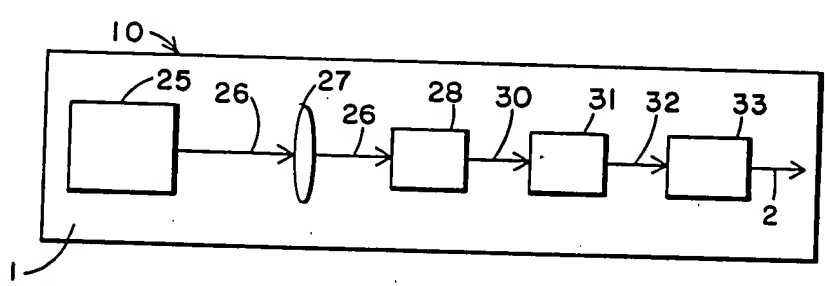


FIG. 2

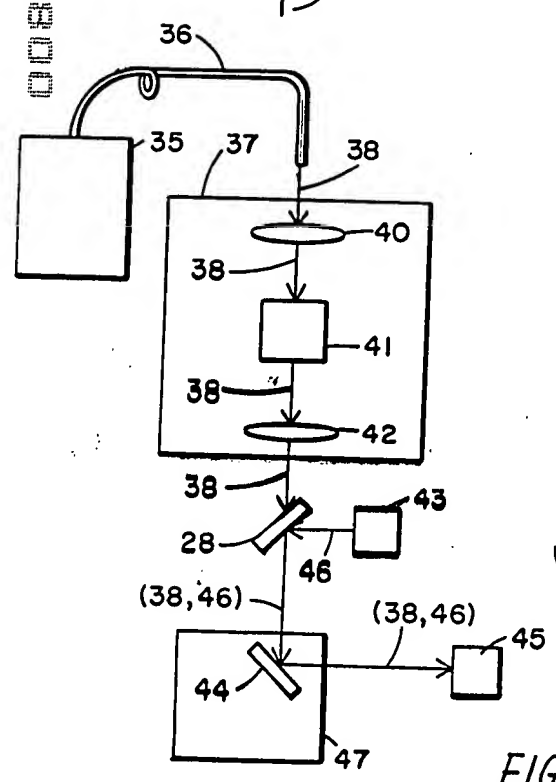


FIG. 3

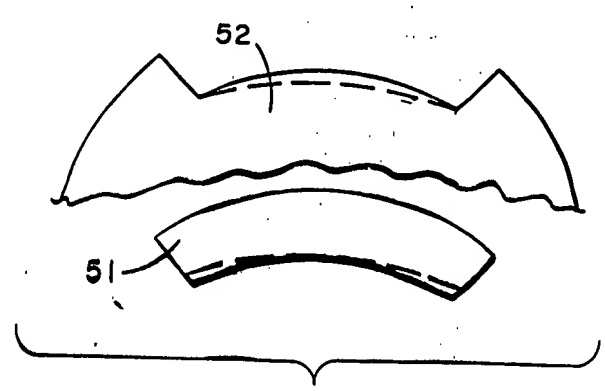


FIG. 5B

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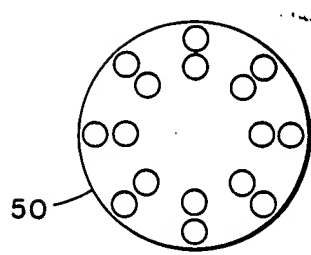


FIG. 4A

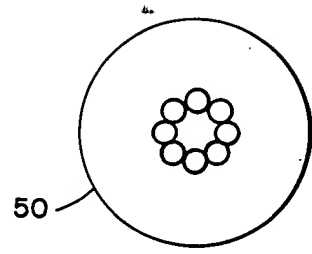


FIG. 4B

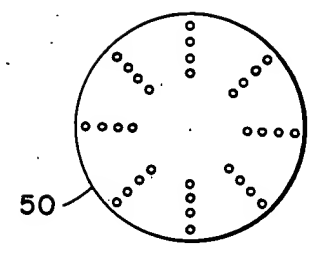


FIG. 4C

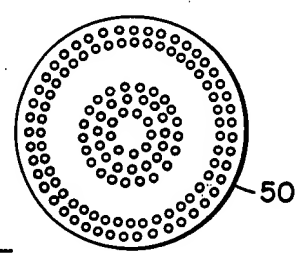


FIG. 4D

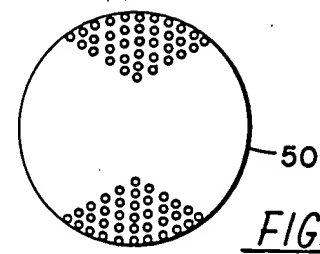


FIG. 4E

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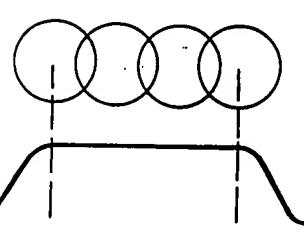


FIG. 6A

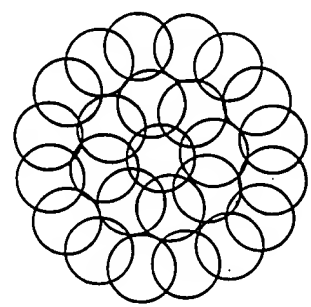


FIG. 6B

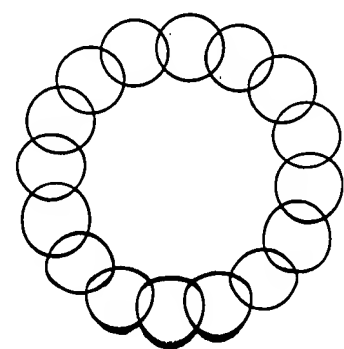


FIG. 6C

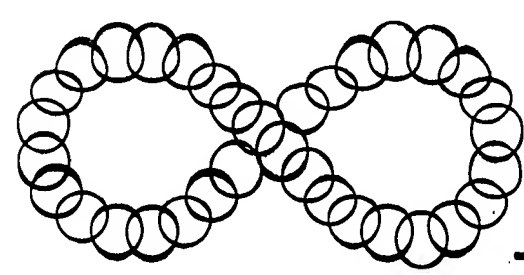


FIG. 6D

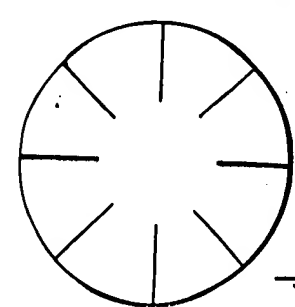


FIG. 7A

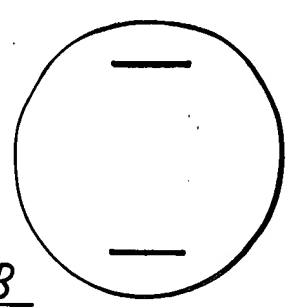


FIG. 7B

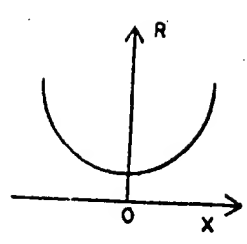
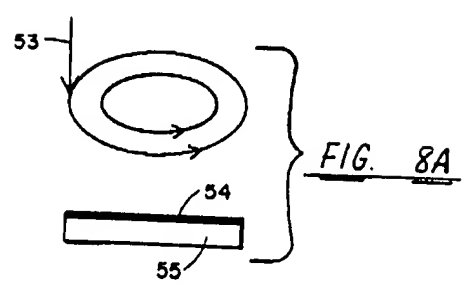


FIG. 8B

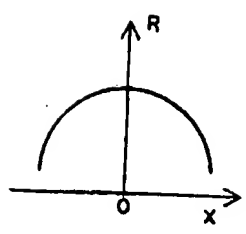


FIG. 8C

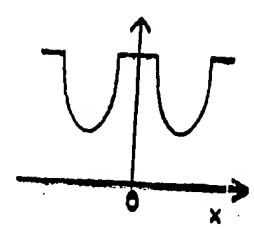


FIG. 8D

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